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This research has two objectives. The first objective is to develop two innovative surface damping treatments: microcellular foams and active standoff constrained layer treatments (ASCL). The second objective is to conduct fundamental studies on surface damping treatments for beams, plates, and shells. Results of this research have led to 5 publications in peer-reviewed archival journals. The project also supports 2 PhD students and 3 MS students. Among these 5 students, 2 were female.

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ENCLOSURE 1

FINAL REPORT

Surface Damping Treatments: Innovation, Design, and Analysis

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STATEMENT OF PROBLEMS STUDIED

Presence of vibration and noise in various defense applications, such as jet fighters, helicopters, and combat vehicles, continues to call for innovative damping treatments that will provide significantly better damping performance. At the same time, a lack of fundamental understanding about two- and three-dimensional passive and active damping treatments continues to hinder the development of accurate models in computer-aided design and rapid prototyping. Motivated by these needs, this research project has two objectives. The first objective is to develop two innovative surface damping treatments: microcellular foams and active standoff constrained layer treatments (ASCL). The second objective is to conduct fundamental studies on surface damping treatments for beams, plates, and shells.

For microcellular foams, we proposed to use them as damping layers or standoff layers to increase damping performance of constrained layer treatments. When used as a damping layer, microcellular foams are compressed so that the microcellular bubbles are compressed forming microcracks to increase the internal damping. In addition, acoustic attenuation of microcellular foams is measured experimentally.

For active standoff layer treatments, the research consists of three parts. The first part is to develop models to evaluate how a continuous yet deformable standoff layer affects damping of a constrained layer treatment. The second part is to study how presence of slots in the standoff layer affects damping of a constrained layer treatment. Finally, the third part is to integrate passive slotted standoff layer treatments with active piezoelectric damping to reduce structural vibration.

The proposed fundamental research on beams, plates, and shells include the following items. The first part of the study focuses on thickness deformation and boundary conditions of beam structures. Then, a new finite element model is developed to predict response of constrained layer shell treatments. Finally, damping of nitenol-aluminum metal matrix composite is studied experimentally.

RESEARCH ACCOMPLISHMENTS

1. For microcellular foams, our research efforts have led to the following findings.

- Microcellular foams have high storage modulus (100 MPa to 1 GPa) but low loss factor (6% to 8%). Therefore, microcellular foams do not have high enough damping to qualify as a

damping material.

- We have developed a manufacturing process to collapse the bubbles in microcellular foams. The process consists of high mechanical pressure, annealing above the glass transition temperature, and thermal cycling. The collapsed microcellular foams, however, do not have larger loss factors. To increase the loss factor, an initial preload might be needed to completely close the collapsed bubbles.
- Microcellular foam is an excellent material for standoff layers. It can increase the damping of constrained layer treatments by 80% with only 2% of weight penalty.
- Micorcellular foams have good sound absorption coefficients (from 0.5 to 0.8) at specific frequencies, which depend on the bubble size and number of layer of microcellular foams. Therefore, microcellular foam can be engineered to attenuate acoustics at certain frequency by changing its bubble size and foam density.
- The above results have been accepted by *Journal of Cellular Polymers* for publication as a full paper.

2. For active standoff constrained layer (ASCL) treatments, we have achieved the following research accomplishments.

- Have developed a mathematical model for passive standoff layer damping treatments with the assumption that the standoff layer has finite bending and shearing rigidity. Have validated the mathematical model with calibrated experiments. The results have appeared as a full paper in *ASME Journal of Vibration and Acoustics.*
- Have developed a mathematical model for passive slotted standoff layer damping treatments. We are now writing Matlab codes to perform numerical simulations. Will develop an experimental setup for model validation soon.
- Have produced a working prototype to demonstrate the feasibility of active constrained layer treatments. We are currently performing finite element analysis to verify experimental results. Initial results indicate that the curvature of the constraining layer above the slotted portion of the standoff layer can increase or decrease damping significantly.

3. For fundamental studies of damping treatments for beam structures, the research has led to the following findings.

- The Mead-Markus model, which has been used for modeling constrained layer treatments for almost 30 years, could result in significant errors for some boundary conditions. We correct the Mead-Markus model by posing more accurate boundary conditions, and verify the improvements through experiments. The results have appeared in *ASME Journal of Vibration and Acoustics* as a technical note.
- Experimentally demonstrated and quantified the existence of thickness deformation in constrained layer treatments. Thickness deformation could be significant in partial treatments. The thickness deformation is predicted using a model developed by Miles and Reinhall in 1986. Theoretical predictions agree well with experimental results. The results have also appeared in *ASME Journal of Vibration and Acoustics* as a full paper.

4. For fundamental studies of damping treatments for plate and shell structures, our research has led to the following achievements.

- Have developed an 18-node, degenerate constrained layer element for plate and shell

structures. For thin plate structures, numerical results show that the isoparametric element can predict natural frequencies, loss factors, and mechanical impedance as accurate as NASTRAN with substantially fewer elements. For thin shell structures, applications of the isoparametric formulation are possible, if spurious mode control can be implemented. The results have been accepted for publication in *AIAA Journal* as a full paper.

- Experimentally measured the damping of nitenol-aluminum metal matrix composite. Our experimental results indicate that nitenol-aluminum metal matrix composite presents significant passive damping compared with other structural materials (e.g., 1% at 20°C and 2% at -20°C). In addition, the damping can be turned on or off by temperature control.

LIST OF PUBLICATIONS

- J. M. Yellin, I. Y. Shen, P. G. Reinhall, and P. Huang, 2000: An Analytical and Experimental Analysis for a One-Dimensional Passive Stand-Off Layer Damping Treatment, *ASME Journal of Vibration and Acoustics*, Vol. 122, No. 4, pp. 440-447.

- P. Huang, P. G. Reinhall, I. Y. Shen, and J. M. Yellin, 2001: Thickness Deformation of Constrained Layer Damping -- An Experimental and Theoretical Evaluation, *ASME Journal of Vibration and Acoustics*, Vol. 123, pp. 213-221.

- Y. S. Jeung and I. Y. Shen, 2000, "Development of an Isoparametric, Degenerate Constrained Layer Element for Plate and Shell Structures," AIAA Journal, (accepted for publication).

- P. Huang, P. G. Reinhall, I. Y. Shen, 2001: A Comment on Boundary Conditions in the Modeling of Beams with Constrained Layer Damping Treatments, *ASME Journal of Vibration and Acoustics*, Vol. 123, pp. 280-284.

- P. Huang, P. G. Reinhall, I. Y. Shen, and V. Kumar, 2000, "Use of Microcellular Foam Materials in Constrained Layer Damping Treatments," *Journal of Cellular Polymers*, (accepted for publication).

SCIENTIFIC PERSONNEL

1. I. Y. (Steve) Shen, Associate Professor, PI
2. Per G. Reinahll, Associate Professor, co-PI
3. Peter Huang, PhD, graduated in September 2000.
4. Jessica M. Yellin, fourth-year PhD student, expected to graduate in December 2001.
5. Paula Beardsley, MS, graduated in June 2001.
6. Eric Rubio, first-year MS student, expected to graduate in June 2002.
7. Ming-Der Yu, first-year MS student, expected to graduate in June 2002.

REPORT OF INVENTION

None